

# Occupational Safety and Health Implications of Increased Coal Utilization

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An area of major concern in considering increased coal production and utilization is the health and safety of increased numbers of workers who mine, process, or utilize coal. Hazards related to mining activities in the past have been especially serious, resulting in many mine related accidental deaths, disabling injuries, and disability and death from chronic lung disease. Underground coal mines are clearly less safe than surface mines. Over one-third of currently employed underground miners experience chronic lung disease. Other stresses include noise and extremes of heat and cold. Newly emphasized technologies of the use of diesel powered mining equipment and the use of longwall mining techniques may be associated with serious health effects. Workers at coal-fired power plants are also potentially at risk of occupational diseases. Occupational safety and health aspects of coal mining are understood well enough today to justify implementing necessary and technically feasible and available control measures to minimize potential problems associated with increased coal production and use in the future. Increased emphasis on safety and health training for inexperienced coal miners expected to enter the work force is clearly needed. The recently enacted Federal Mine Safety and Health Act of 1977 will provide impetus for increased control over hazards in coal mining.

## Executive Summary

An area of major concern in considering increased coal production and utilization is the health and safety of those who mine coal or subsequently process coal. Greatly increased production of coal in the United States under either the National Energy Plan or business as usual will expose larger numbers of workers to the health and safety hazards of coal mining. Such hazards in the past have been serious resulting in many mine-related accidental deaths and disabling injuries. Disability and death from chronic lung disease among coal miners have also been excessive.

The Federal Coal Mine Health and Safety Act of 1969, designed to reduce health and safety hazards,

for the first time in this country mandated environmental controls in the workplace to reduce the risks of chronic lung disease. Although conditions in the mining industry have improved as a result of the implementation of these reforms, considerable doubt exists as to the achievement of maximum compliance. The excesses in respiratory disease associated with coal mining indicate the need for more comprehensive medical surveillance of coal miners.

Underground coal miners experience increased mortality from both occupationally induced lung diseases and accidental deaths. In addition, there is increasing concern in regard to a possible increased risk of death from stomach cancer among underground coal miners. Coal workers' pneumoconiosis and associated chronic bronchitis, emphysema, and airways obstruction, affect over a third of our currently employed underground coal miners. Surface miners have been found to have substantially less respiratory disease than underground coal miners. Noise and occupationally induced hearing loss are

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also commonly found in underground coal mines. Noise in surface mining is again less than in the confined spaces of underground mines. Cold and heat stress are more commonly found in surface mining and although these effects may be serious, they are amenable to readily available control technology. Two newly emphasized coal mining technologies, the use of diesel powered mining equipment and the use of longwall mining techniques, may be associated with potentially serious health effects. Coal-fired power plants are also associated with exposure to noise and respiratory disease risk from exposure to coal dust, SO<sub>2</sub>, NO<sub>2</sub>, and asbestos.

As is the case with occupationally induced diseases, underground coal mines are clearly less safe than surface mines. Fatalities are consistently higher and disabling injuries consistently greater among underground as opposed to surface coal miners. Principal causes of fatalities in underground coal mines are roof falls, haulage-related accidents and other machinery-related accidents. The large number of inexperienced miners entering the workforce with increased coal production may well drive the fatality and injury rates up. Increased emphasis on safety and health training for inexperienced coal miners entering the work force is clearly needed.

A review of the current health and safety record in coal mines and projections based upon this experience to estimate what might happen if increased coal production is not accomplished by adequate measures to protect workers are of concern. It is clear that strong preventive measures are necessary to reduce health and safety risks of miners, particularly as our reliance upon coal as an energy source increases in future years. The occupational safety and health aspects of coal mining are understood well enough today to justify implementing the necessary control measures so that potential problems associated with increased coal production do not become magnified in the future. The recently enacted Federal Mine Safety and Health Act of 1977 should provide additional impetus for the control of hazardous exposures in coal mines.

## Introduction

Our nation's dependence upon coal as an energy source has gradually declined in the decades following the peak years of coal production and usage early in this century. Now, the United States is looking once again toward coal to meet the bulk of our growing energy needs.

Planning for a major switch from oil and gas to coal requires a careful examination of the health and safety implications of this conversion for the work-

ing men and women who mine coal or participate in the utilization of this fossil fuel.

Death, disease, and disability have always been associated with the mining of coal. It is estimated that more than 100,000 miners have lost their lives in mining accidents since 1900. In the past, health effects have included skin disease, eye afflictions, arthritic joints, Weil's Disease spread by rats, tuberculosis, and typhoid fever. Even more serious than these, although not widely recognized until relatively recently, were the chest diseases — coal workers' pneumoconiosis (CWP), and associated chronic bronchitis and emphysema. The Federal Coal Mine Health and Safety Act of 1969 was designed to reduce occupational health and safety risks, and for the first time in this country mandated strong environmental controls to reduce the risk of chronic lung disease among coal miners. Although conditions in the mining industry have improved as a result of the implementation of these reforms, considerable doubt exists as to the achievement of maximum compliance.

The President's Energy Message called for a study of the health and environmental effects of increased coal production and use. The Secretary of Energy, in turn, requested that the Department of Health, Education, and Welfare take the lead in forming a committee of experts to assess the health and ecological effects of increased coal utilization. The initial charge to the committee was to define and commission the preparation of papers to review the current state of knowledge on key topics related to the health and environmental effects of increased coal utilization. The information contained in these papers is to contribute to the development of an overall policy report by the committee to the President. The key question being asked is what are the health and environmental implications of utilizing additional quantities of coal as a result of the National Energy Plan. One of the subjects for which papers were commissioned deals with the occupational safety and health aspects of increased coal utilization. The following report on occupational safety and health issues was prepared primarily by the staff of the National Institute for Occupational Safety and Health (NIOSH) with assistance from the Federal Coal Mine Health Research Advisory Committee, as well as the Department of Energy, the Mine Enforcement and Safety Administration, and the Environmental Protection Agency. In addition, comments generated by public hearings related to this report were taken into account in revising an earlier draft of this document. Particularly important in this regard were comments by the National Coal Association, the American Mining Congress and the United Mine Workers of America.

## Underground and Surface Coal Mining

### Health Effects of Underground Coal Mining

Epidemiological studies of diseases of underground coal miners fall into two categories: morbidity and mortality studies. Mortality studies offer the investigator an opportunity to assess the impact on mortality of chronic disease such as coal workers' pneumoconiosis (CWP) or diseases which may have long latent periods such as stomach cancer. Such studies rely upon a "late" and accordingly an insensitive indicator of disease and death in an earlier generation, which may have been exposed to quantitatively different risks than the current generation of miners. Mortality patterns of underground coal miners have, however, given us a reasonably consistent picture of cause specific mortality.

Cross-sectional and prospective morbidity studies allow for more sensitive "early" measures of health effects, such as assessment of respiratory symptoms, ventilatory capacity, and hearing acuity and more importantly provide an opportunity to correlate health effects with occupational exposure. Both of these broad areas of investigations have only recently addressed health effects of underground coal miners in this country and, therefore, leave many important questions only partially answered.

**Mortality Patterns of Underground Coal Miners.** British recognition of coal workers' pneumoconiosis and associated problems preceded that in the United States. Hence their studies begin at a much earlier period than similar studies in the United States. In 1948, Fletcher (1) found standardized death rates of coal miners in England and Wales for all respiratory diseases except tuberculosis, when compared with those rates for all occupied and retired males, showed a marked excess for the four periods, 1900-02, 1910-12, 1921-23 and 1930-32. Davies et al. (2) traced 3435 coal miners alive in 1931 through 1945. Of those with "early disease," 60% survived 10 years, but only 25% of those with "advanced disease," survived 10 years. This is compared to an 85% expected survival rate based on the 1931 English Life Table. Henry, Kennaway, and Kennaway (3) published data showing no excess of deaths from cancers of the bladder or prostate in 1921-28 for coal miners in England and Wales; in 1937 Kennaway and Kennaway (4) published data showing deficits of about 40% for deaths attributed to cancers of the lung and of the larynx for coal miners during the period 1921-38. Cochrane, et al., in 1950-51 and again in 1953 examined over 20,000 residents of Rhondda Fach, a mining valley in South

Wales (5) and have since reported on their mortality after 6 years (6) and on proportions of survivors after 20 years (7). They found a sharp reduction in the number of miners with complicated CWP who survived after 20 years, compared to miners with no or with simple CWP.

Death rates by usual occupation computed for 1950 in the United States, based on occupations reported to the 1950 census, showed coal miners to have marked excesses in death rates (8): 95% for all deaths, 77% for influenza and pneumonia, 168% for tuberculosis, 1027% for other nonmalignant respiratory diseases, 136% for stomach cancer, 92% for cancer of the trachea, bronchus and lung and 71% for bladder cancer. Enterline (9) also reported, based on actuarial insurance estimates for 1949-1963, excesses of 72% for all coal miner deaths and 1011% for deaths due to respiratory diseases and tuberculosis.

In the United States, Matolo et al. (10) found that age- and sex-adjusted incidence of gastric cancer from January 1965 to January 1969 in the only two coal mining regions in Utah was four times that of the State of Utah. The incidence of gastric cancer in coal miners was three times that of non-coal miners living in counties with coal mining and at least eight times that of males in counties with no coal mining. Neither diet, socioeconomic class distribution, nor ethnic, religious or social background appeared to be related to the increased cancer incidence.

A later American study by Creagen et al. (11) disputes an association between mining and an increased rate of cancer of the stomach and suggests that the correlation is with socioeconomic class rather than with occupation. In this work, mortality from gastric cancer in 23 coal mining counties in seven states of the United States during 1950 to 1969 was compared with other counties. Populations were carefully matched by educational level and median income. While observed deaths from gastric cancer were 20% to 30% greater than expected for men and women (statistically higher significant), a similar excess was noted for lung and cervical cancer, tumors related to lower socioeconomic class. Fewer deaths occurred as a result of leukemia, and breast and colon cancers, tumors which are associated with higher social class.

In 1973, Ortmeier, Baier, and Crawford (12) studied 4000 coal miner beneficiaries in Pennsylvania. The bituminous coal miners showed no excess deaths but the anthracite miners showed a 27% excess. Beneficiaries with categories B and C or complicated CWP of severe airways obstruction ( $FEV_1/FVC$  less than 55%) showed excesses in deaths (greater for anthracite than for bituminous miners); miners not qualifying by these criteria showed no excess in deaths. In 1974, Ortmeier and

Table 1. Summary of deaths by neoplasms.

Senior author and/or investigator	Area of study and population studies	Site of cancers	Estimate of excess (+) or deficit (-) deaths, %
Doll (15)	Four districts of S. Wales 15,247 men, aged > 15 years	Lung	-52
Goldman (16)	Rhondda Fach valley, S. Wales. Adult male residents	Lung	
	Coal Miners		-19
	Not coal miners		-47
Goldman (16)	England and Wales (Registrar General's data)	Lung	
	Underground coal miners		-30
	Surface coal miners		-08
Stocks (17)	England and Wales (Registrar General's data):	Stomach	+49
	Coal Miners 1949-53		
Adelstein (18)	England Wales (Registrar General's data).	Stomach	+25
	(Registrar General's data).	Lung, bronchus,	-29
	Employed and retired coal miners, 1959-65	trachea	
		Bladder	-23
		Prostate	-28
Liddell (19)	England and Wales. All decedents aged 20-64 currently employed or previously employed in coal mining		
	Face		-51
	Other underground	Lung and bronchus	-47
	Surface		-18
	Face		+01
	Other underground	Stomach	+28
	Surface		-68
Enterline (8)	United States (National Vital Statistics).	Stomach	+175
	Employed and retired coal miners aged	Lung, bronchus	+92
	20-64 (5,793 deaths).	trachea	
		Prostate	+106
Enterline (9)	United States (Actuarial studies); insured men	All cancers	-20
	in coal mining as last occupation, 1949-63.		
Costello et al. (20)	Samples of employed and ex-miners, Appalachian region, 1963-71.	Lung	-33

Costello and associates (13) published findings for probability samples of 2550 employed and 1177 former bituminous coal miners in the Appalachian region initially examined by Lainhart and associates (14) in 1963-65. They found consistent and significant excesses in mortality for miners with complicated CWP or with airways obstruction and for miners who were cigarette smokers at the time they were examined. They also found that among miners with simple and complicated pneumoconiosis, that age-adjusted mortality was greater for those working 30 years or more than for those working less than 30 years, but no difference in mortality was found for miners with no CWP who worked 30 or more years. Table 1 summarizes studies of deaths attributed to malignant neoplasms (cancers) among coal miners indicating whether excesses (+) or deficits (-) were observed.

In 1975 Rockette published findings from a mortality study of 22,998 coal miners, representing a 10% probability sample of all coal miners eligible for benefits from the United Mine Workers of America Welfare and Retirement Funds as of January 1, 1959 (21). The sample population was traced through the year 1971, and was compared to all males in the U.S.

for 1959-71 as a control. The significant excesses in mortality reported by Rockette are summarized in Table 2. Deaths due to accidents reported for 45 occupational groups indicate that between 1954-1964 coal miners ranked with lumbermen, structural iron workers, other miners (non-coal), and oil and gas field workers as the five occupational groups with the highest relative accident death rates (22).

The principal problem in a review of mortality study findings is that each study is of necessity re-

Table 2.

Deaths attributed to:	Excess mortality, %
Influenza	+90
Emphysema	+44
Asthma	+75
Tuberculosis	+46
Accidents	+44
"Ill-defined causes"	+88
Malignant neoplasms (cancers)	
Respiratory organs	+13
Stomach	+35
Hypertension	+17

stricted to available data. Deceased workers can be neither reinterviewed nor reexamined. In addition to this barrier, authors of the principal studies reported here and of special analyses of mortality study procedures, have pointed out the following principal qualifications of findings.

(1) Variations by region or nation in chronic diseases, e.g., in lung cancer, other cancers, or chronic bronchitis, for all adults are inadequately taken into account when comparing studies from different areas and trying to estimate by how much "excesses" are due to occupational factors. Excesses and deficits are measured by the degree to which the number of deaths counted over a specified time period in a study group exceed or fall short of the number of deaths that might have been expected during the same time period had the workers in the study group died at the same age-sex specific rates as did persons in same population selected as a control. The ideal control population, (which is rarely available) is one whose exposures match those of the study group in all respects except the occupational risk factors being studied. Death rates of employed populations tend to be lower than those for not employed. If observed deaths are taken from an employed population but expected deaths are computed from a total population, including the not-employed, the ratio of the two may be lower by about 20 percent than it would be if the control population were made up only of employed persons (23).

(2) In addition, death certificates are inadequate sources of data for establishing the prevalence of chronic conditions such as the pneumoconioses, emphysema, diseases of the heart, tuberculosis and cancers by original site. Evidence detailed elsewhere (24) indicates that, for the above conditions, autopsy findings will report underlying causes of death not reported on death certificates in from 10 to 30% of cases, and that death certificates will report those conditions as "contributing" to death in only 50 percent or less of the cases for which they are reported at autopsy. Histological, autopsy and clinical data are badly needed in any mortality study where one or more of these conditions is a critical indicator of disease from occupational exposures.

Even though mortality studies of coal miners suffer from impreciseness in linking exposures to dust or other occupational hazards to subsequent chronic diseases and impairment there is agreement on the following conclusions.

Death rates of coal miners, including former coal miners, in the most recent studies (Cochrane, Rockette, Ortmeyer and Costello) are somewhat higher (about 20-30%) than those of other adult employed and formerly employed men in the same area populations. However, evidence from the periods before

1950 indicates that overall excesses in coal miner death rates were greater than they are in more recent studies.

Death rates of coal miners with radiographic evidence of simple pneumoconioses are no higher than those of miners with no evidence of pneumoconiosis; however, death rates of miners with evidence of complicated pneumoconioses are significantly greater than rates for other miners.

Coal miners who smoke cigarettes suffer higher death rates than miners who do not smoke.

Death rates attributed to stomach cancer and those attributed to non-malignant chronic respiratory diseases (chronic bronchitis, emphysema, etc.) are higher among coal miners than among the general male population.

Rates of death due to accidents occurring in underground mining are decidedly higher than among employed men in general, and are as high as other "high-risk" occupations — e.g., lumbering, other (not coal) underground mining, and structural iron workers.

It is uncertain whether or not there are "excesses" of coal miner death rates attributed to lung cancer and whether or not overall coal miner death rates are "excessive" compared to industrial populations not exposed to coal mining either underground or on the surface.

Among current research needs are the following: (1) medical review by autopsy of the presence or absence of diseases of interest in occupational mortality studies of coal miners; (2) use of data existing in Federal or State agency files — work histories, evaluations for disabilities, dates of birth, sex and race, residence, to more completely study mortality among coal miners; (3) special studies to detect and measure biases in control groups used in mortality investigations of coal miners; (4) further epidemiological and experimental studies to address the etiology of mortality from stomach and lung cancer among coal miners; (5) studies to assess the impact of trace metals in coal such as arsenic, lead, beryllium and cadmium upon mortality patterns in coal miners.

**Morbidity Studies of Health Effects of Underground Miners.** There are three major areas of concern in regard to health effects: coal workers' pneumoconiosis and associated chronic bronchitis and emphysema; occupationally induced hearing loss; and exposure to diesel emissions (emerging as a potential problem). The previous record of high rates of infectious diseases among miners has been largely reversed although influenza and tuberculosis still appear as somewhat excessive causes of death (21). Degenerative arthritis amongst miners has largely disappeared with mechanical mining equipment and

a younger mining workforce, but continues to occur where low seam coal is mined.

**COAL WORKERS' PNEUMOCONIOSIS, CHRONIC BRONCHITIS, AND OBSTRUCTIVE LUNG DISEASE:** There are two forms of coal workers' pneumoconiosis (CWP): simple CWP and complicated CWP or progressive massive fibrosis (PMF). In the first NIOSH National Study of Coal Workers' Pneumoconiosis, which included over 10,000 underground miners and was conducted between 1969-71, 30% were found to have x-ray evidence of some category of CWP (25). Since that time, routine medical examinations conducted by the NIOSH Appalachian Laboratory for Occupational Safety and Health on over 80,000 miners from 1975-77, including a high proportion of new miners, reveal a CWP prevalence of 7% (26). The reasons for this apparent disparity are many and include probable over-reading of films in the former study, an influx of new miners into underground mines since the energy shortage in 1973, and possibly a real reduction in CWP as the result of reduced dust levels in coal mines, especially following passage of the 1969 Federal Coal Mine Health and Safety Act. Full compliance with the 2 mg/m<sup>3</sup> coal dust standard, however, has not yet been fully achieved.

Based upon the second round of the National Study of Coal Workers' Pneumoconiosis which studied a cross section population of underground coal miners with a broad range of exposure to coal mine dust, and the results of the entire medical surveillance program, it is estimated that between 10% and 15% of the current underground work force has some category of CWP (27). This estimate probably represents an underestimation of the incidence of CWP in the United States as it does not include a significant number of former miners with CWP.

It is of significance that CWP varies with region, appearing to be higher in the East and lower in the West (25, 28), and not accounted for by differences in length of exposure. Another report related simple and complicated CWP to the chemistry of coals using a bioassay system. In essence, the inference was made that the prevalence and incidence of CWP is associated with the chemical composition of coals (29). The prevalence of PMF varies accordingly and has been found to be particularly high among the anthracite miners in Eastern Pennsylvania (28).

Epidemiological studies in Great Britain have been of major importance in developing the current U.S. 2 mg/m<sup>3</sup> respirable dust standard (30). Too little time, however, has passed since implementation of this standard, to assess its effectiveness in controlling CWP.

Chronic bronchitis has been examined in

epidemiologic studies of coal miners (31). A major cause of this condition is cigarette smoking; however, there is an added effect of coal mine dust exposure which increases the prevalence of bronchitis in both smokers and nonsmokers (32, 33).

Both the intensity and duration of dust exposure appear to be important in the development of chronic bronchitis. The presence of chronic bronchitis appears to be associated with decreased lung function detectable by comparing large numbers of miners with and without this condition (33, 34). Clinically significant decreased lung function occurs not infrequently among smoking miners who constitute the majority of the coal mining work force. Decreased lung function is also found in a small percentage of currently employed miners who have never smoked (33, 35, 36).

It is generally agreed that coal workers' pneumoconiosis is a distinct entity caused by the inhalation and retention of respirable coal mine dust. It is often associated with emphysema and chronic bronchitis which, when combined, can result in significant pulmonary impairment, some of which is attributable to inhalation of coal mine dust and some attributable to cigarette smoking, aging, and other factors. The type of coal mined has a bearing on its biological toxicity, eastern coal being relatively more toxic than western coal. It is estimated that 10-15% of our current underground coal miners have some category of CWP. Respirable dust levels have been reduced since passage of the Coal Mine Health and Safety Act in 1969, but some areas of many mines still exceed the 2 mg/m<sup>3</sup> standard. It is uncertain whether the 2 mg/m<sup>3</sup> coal mine dust standard will adequately control CWP over the working life of coal miners is still in question. The adequacy and appropriateness of personal dust samples used for compliance purposes for correlation with medical data is not clear. What factor(s) in addition to inhalation of coal mine dust result in PMF and what constitutional factor(s) in addition to inhalation of coal mine dust, cigarette smoking, and aging result in the development of chronic bronchitis and airways obstruction are not known.

Research needs include (1) more comprehensive surveillance of CWP, bronchitis, and airways obstruction and correlation with representative and accurate dust levels to assess compliance with and the adequacy of the 2 mg/m<sup>3</sup> standard; (2) more extensive studies of immunological, genetic or other factors which may play an important role in PMF; (3) assessment of the probability of going from CWP category 1 or greater to higher categories of CWP for differing lengths and severity of coal dust exposure; (4) studies, including detailed experimental and

clinical pathological research, to determine the relationships between CWP, airways obstruction, and emphysema; (5) further assessment of CWP among workers in small mines, coal mine construction workers, and strip and auger miners through inclusion in the overall x-ray surveillance program now available to underground miners; (6) more information on the natural history of coal dust induced bronchitis, its relationship to obstructive lung disease, and other constitutional host factors which may be important in its etiology and its effects on life expectancy; (7) studies to better characterize dust in coal mines, including particle size and content of silica and other trace contaminants.

**NOISE AND HEARING HAZARDS IN COAL MINING:** Noise surveys in coal mining have shown noise conditions exceeding current exposure standards for safeguarding hearing, and hearing studies of miners have found them to have measurably worse hearing than comparable groups of workers in quiet occupations (37-41). Despite this evidence, however, the degree of hearing loss for miners is difficult to estimate because of the intermittent, variable patterns of exposure to noise that characterize coal mine routines and other job factors. Quiet interruptions may serve to moderate the noise hazard to hearing (40). On the other hand, a recent NIOSH hearing survey of coal miners indicated more severe hearing losses than expected from noise dose calculations based on current formula for rating exposure time/noise intensity relationships (41). The adequacy of such formulas remains one of the outstanding questions in dealing not only with coal mine hazards to hearing but treating interrupted noise exposures in general (42).

Expanded coal production could heighten the existing noise hazard to hearing in mining in different ways. For example, it could increase the demands for more powerful equipment capable of extracting greater volumes of coal. It also could alter coal extraction methods through quickening the pace of current operations, allowing for fewer or shorter quiet periods. Indeed, the background noise levels during the periods of "quiet" are now increasing to the extent that the intermittent noise pattern is effectively becoming a more continuous one, and therein presenting a more serious threat of hearing damage.

Over 25% of the sample examined in the previously mentioned NIOSH hearing survey of coal miners also revealed ear disorders via a simple otoscopic check (41). Ear inflammations, apparent otitis media, perforated eardrums, impacted wax, and even suspected cholesteatomas were observed. Hearing losses beyond those due to occupational noise were also evident in this group. This inordinate

number of otological disorders has dictated a planned follow-up study to confirm this finding. More importantly, its aim is to provide through differential diagnostic techniques more clinical data on these cases and insights into their causes as possibly related to coal mining (43). In the opinion of the authors of this study, dust in coal mine operations may increase the possibility of ear infections and many outer or middle ear disorders. Recurrent exposures to positive air pressure differentials due to ventilation needs in underground mining which may have adverse effects on tympanic membrane and Eustachian tube functions must also be considered.

It should be recognized that noise standards protective of hearing may still permit noise intense enough to interfere with speech communication and the hearing of other desired sounds (44). For example, hearing the "roof talk" in underground mining operations represents a significant warning signal to miners working in immediate areas. The use of personal ear protectors, even on an interim basis, as a means of preserving hearing may thus be unacceptable since they may attenuate these and other wanted sounds which would be otherwise audible during at least the quiet period of coal mine work routines.

Despite continued emphasis on safety, coal mining, especially that performed underground, is continually ranked among the most hazardous occupations in terms of both the frequency and severity of job injuries (45). Noise conditions of a high level, intermittent type, which are typical to coal mining, have the greatest likelihood for causing distraction and performance error (46). In-depth investigations of mine accidents and injuries, short of mine disasters and fatalities, remain to be carried out to ascertain whether noise may have contributed to such mishaps. An influx of new, inexperienced workers in the mining occupation, coincident with the increased need for more coal output, suggests that such potential problems be addressed.

It is not yet known that exposure time-intensity level formula is most adequate for rating the hearing loss risk from coal mine operations, given the intermittent, varying high level noise patterns that exist, and what noise limits, incorporating this formula, would assure hearing protection to miners so exposed. Also needed is a knowledge of what additional engineering control measures can be developed for quieting coal operations; the nature and cause of the apparent increased frequency of otologic disorders found in coal miners; how aural communication needs in mining can be assured, given the conflicting requirements for hearing conservation with the possible use of ear protectors.

Also uncertain is whether frequency selection hearing protection devices to allow transmission of "roof talk" can be developed? The role of noise as a contributing factor to accident potential in coal mining should be studied.

**NEW COAL MINING TECHNOLOGY — DIESEL:** A technology which has been advanced for increasing coal production from underground coal mines is the increased use of diesel engine powered mining equipment. Only a limited number of diesel-powered units are currently used in U.S. coal mines, but diesels are used extensively in non-coal mines in the United States. The question of whether diesel engines should be used in underground coal mines is controversial, the issues being health effects, safety and productivity. Proponents claim that gains in productivity and mine safety would be realized. There is, however, concern for adverse health effects to miners resulting from exposure to the toxic components of diesel exhaust in addition to substances already present in coal mine air.

At the recent NIOSH Diesel Workshop (47), representatives from several mining countries reviewed their experience with diesel powered equipment in underground mines. At the conclusion of the workshop, it was recognized that there is only limited data on health, safety and productivity aspects of diesels. Health studies which are available investigated relatively short term exposure to diesel emissions in relatively small populations (48-53). None followed the study cohorts long enough to adequately assess cancer risk or chronic respiratory disease risk. *In vitro* and *in vivo* studies are limited in number and scope and show mixed toxicological results (54-57). The workshop, however, concluded that it is important to recognize that the underground coal miner is already compromised with a significant occupational disease burden and that there are potential health effects from diesel emissions which could affect those organs already compromised. These diesel emission components include exposure to polynuclear aromatics, which are difficult to quantitate, but contain known carcinogens, and exposure to oxides of nitrogen, known pulmonary irritants, which may interact with coal dust or diesel particulate to increase deposition and toxic effects within the lung. Concern was also raised in regard to increased noise of a continuous nature which would be introduced by diesel powered equipment. Mucous membrane irritation and odor from phenols, aldehydes, and acrolein from diesel engines were also raised as troublesome but probably not limiting factors. Ergonomic considerations which would encompass the areas of vibration injury, heat and noise were raised as areas where little is known but acknowledged as important to safety and health. Other

components of diesel emissions including CO, CO<sub>2</sub>, SO<sub>2</sub>, and H<sub>2</sub>SO<sub>4</sub> must also be considered but may not be major problem at levels currently found in underground mines.

Research needs identified at the NIOSH Diesel Workshop (47) include but were not limited to the following. (1) Engine design and fuel factors, duty cycles, and emission control technology all of which affect the emissions of potentially toxic substances from diesels require study. (2) The interaction of exhaust pollutants with mine air components needs further study and the environment in coal mines where diesels are used must be accurately characterized. (3) Epidemiological investigation of mortality in a large cohort exposed to diesel emissions for over 20 years is needed to assess potential cancer and chronic respiratory disease risk. (4) *In vivo* and *in vitro* studies of diesel emissions in concentrations produced by mine production equipment and in combination with coal mine dust are particularly important. (5) Ergonomic studies of diesel versus electrical powered mining equipment would allow proper assessment of noise, vibration, heat as well as safety risks. (6) Productivity of diesel as opposed to electrical systems needs further assessment and quantification.

**New coal mining technology — longwall:** The use of longwalls is expanding as a system of underground coal mining because of the potential gains in productivity. Unfortunately, there may be serious health hazards related to the use of longwalls.

The portion of underground coal produced with longwalls rose steadily from 2.1% to 3.6% during 1970-1975 and the number of active longwall units increased from 40 to 72 during the last four years. Equipment manufacturers predict that there could be 140 active longwall units by 1981 (58). While accurate statistics are not available, it is estimated that average production on longwall units is about 700 to 900 tons per shift (58). This is over twice the average shift tonnage from all types of underground coal production units.

The latest available data from respirable dust samples taken by mine operators indicates that, although only about 6% of all underground production units (sections) currently exceed the 2.0 mg/m<sup>3</sup> standard, about 14% of the longwall units currently exceed this standard. Data from 1976 shows that 16 of 21 longwall double drum shearer units exceed the 2.0 mg/m<sup>3</sup> respirable dust standard. Several of these units had dust levels exceeding 4.5 mg/m<sup>3</sup> with the highest exceeding 18 mg/m<sup>3</sup>. Another problem is that, whereas the exposure is high respirable dust levels on continuous miner units is usually limited to the loading crew (2-4 miners per shift) before the dust laden air is exhausted from the working area, this is



not normally true on longwall units where the dust laden air passes over most of the crew (up to 10-12 miners per shift).

It is interesting to note that in Europe, where longwalls are the predominant means of mining coal, the respirable dust standards are much higher than our 2.0 mg/m<sup>3</sup> standard (i.e. about 4.5 mg/m<sup>3</sup> in England). In Australia it is reported that, while their respirable dust standard (175 particles/cm<sup>3</sup>, which cannot be directly correlated with our gravimetric standard) satisfactorily safeguards the miners' health and normally can be met without undue technical difficulty or cost, there is a problem controlling dust on longwall faces in thick seams.

Noise surveys made on longwall double drum shearer units indicate that the normal dBA levels to which shearer operators were exposed ran from about 95 to 105. This would only allow from about one to four hours of operation before the noise exposure standards would be exceeded. Units with good production will often exceed this time.

The usual respirable dust controls are ventilation and spray water, with ventilation normally playing the larger role. Other controls currently under investigation for longwall units include: redesign of the speed and depth of cut of the shearer, intergral dust collecting, remote control, and infusion to pre-wet the coal. Since the use of ventilation is not effective on longwall (in fact, increased ventilation may increase dust concentrations) and since the use of redesign, intergral dust collection, remote controls and infusion are in their infancy in American coal mining, the development of respirable dust controls specially aimed at longwall dust problems appears to be the most pressing need. Information leading to redesign of longwall shearers and panlines in order to incorporate noise reduction technology is also required.

**BEHAVIORAL FACTORS:** Since the mining of coal requires a large capital investment in equipment it is expected that increased production will result in a subsequent increase in the number of employees working shifts. A recent NIOSH report indicates that approximately 18% of the workers in energy related industries (coal and petroleum products) are currently employed on some type of work shift other than day schedule (59). Based on previous research linking shiftwork to increased morbidity and accidents (60, 61), it is suspected that an increase in work-related illnesses and accidents may occur in relation to the increase in shiftwork scheduling. In particular, rotating shifts appear to present the most serious threat to worker health and safety (61, 62). In this regard, efforts to conserve energy by encouraging general industrial production at night to coincide with off-peak lower electrical rates may also pose shift work problems.

Increased production of coal may introduce a number of production pressures which can be expected to affect employee job stress levels. Research indicates that coal miners have a high incidence of morbidity and mortality from stress related disorders (63-65). A recent NIOSH study indicated that coal miners reported significantly greater levels of psychological distress related to work than other blue collar workers (65). This distress was found to be related to workload. Thus increases in production which increase workload may serve to exacerbate already high levels of job stress and strain for coal miners.

Increased coal production may involve an increase in overtime hours worked, a greater emphasis on shiftwork, increased numbers of inexperienced miners, and increased employee contact with work hazards. Such factors produce fatigue due to longer working hours. Inattention or loss of attention due to fatigue or changes in biological rhythms, and increases in overall employee stress level may produce increases in accidents. A recent NIOSH technical report which reviewed the scientific literature related to causal factors in accidents indicated that increases in working hours produce increases in the incidence of industrial accidents. The increases in accidents can be related to worker fatigue and loss of attention (66). A second NIOSH supported study indicated that shiftwork systems can influence the incidence of industrial accidents. This study showed that employees on a rotating shift system had significantly more accidents than employees working days or on a fixed shift (61). A third NIOSH study showed that increases in overall stress level have a significant influence on the incidence of industrial accidents. The greater the perceived stress level, the greater the incidence of industrial accidents (67). In conclusion, it can be expected that there may be an increase in the number of health and safety problems related to behavioral factors if coal production is increased.

## Health Effects of Surface Mining:

There are two major categories of adverse health effects among surface coal miners: (1) coal workers' pneumoconiosis, chronic bronchitis and airways obstruction; and (2) heat and cold stress. Other potential hazards, such as exposure to asbestos in mine operations and from insulating asbestos blankets used in welding operations and welding fumes themselves, must be considered. The severity of these exposures and their biological effect have not been adequately quantified. Inadequate drinking water and lack of bath and change houses are also potential

hazards associated with surface mining and the reclamation of strip mines.

**Coal Workers' Pneumoconiosis, Chronic Bronchitis and Airways Obstruction.** Only one epidemiological study of respiratory hazards encountered by surface coal miners has been completed in the United States (36).

In this study, NIOSH's Appalachian Laboratory examined 1,438 surface coal miners. Four percent (59 miners) showed radiographic evidence of pneumoconiosis but only seven miners, five of whom had previous underground experience, had x-rays which showed severe pneumoconiosis (category 2 or greater). Of those doing miscellaneous surface work and who had never worked underground or had only brief underground exposure, but who worked for an average of 20 years, only 2.2% had radiographic evidence of CWP. Those with dustier surface jobs such as tipplesman, driller or cleaner with over 10 years exposure had a 7.7% prevalence of CWP. Roughly a third of the study population had previous underground experience and of those with greater than 10 years underground, 11.2% had x-ray evidence of CWP. Significant decreases in pulmonary function related to concentration of surface mine dust were found among smoking miners. Increased rates of bronchitis were, however, observed among both smokers and non-smokers and appeared to be related to years of exposure in surface mining.

From this one investigation it appears that surface miners experience the same respiratory diseases as underground miners, but except for specific dusty jobs, the dust exposure is clearly less than that of underground miners.

The frequency and severity of CWP, chronic bronchitis and airways obstruction is significantly less among surface as compared to underground miners.

It is uncertain whether the 2 mg/m<sup>3</sup> dust exposure standard for health protection for underground coal mines is applicable to surface mines. The extent to which other operations such as exposure to asbestos and welding fumes may be contributing to pulmonary dysfunction in surface coal miners is unclear, as is the role, if any, of diesel emissions in causing respiratory or other occupational diseases in surface coal miners.

Research needs include more extensive epidemiological studies of surface mining to ascertain the full extent of respiratory disease as well as other medical conditions such as hearing impairment. Collaborative occupational exposure studies of surface mines are needed to quantitate dust levels, noise levels, welding fume exposure, asbestos exposure, and exposure to diesel emissions. Increased medical sur-

veillance of surface miners is needed to detect CWP and other medical problems.

**Cold/Heat Stress.** Occupational cold or heat stress results when the body is unable to accommodate temperature, humidity, and work intensity demands. Cold and heat stress occurrences in coal mining have not been documented extensively. Underground mine conditions vary somewhat with outside air temperatures. The depths of underground coal mines in the U.S. do not yield the hazardous heat conditions found in South African coal mines (68). In a study of 23,000 British coal miners (69), lost time due to sickness was 63% higher in miners working at temperatures above 80°F than in those working in temperature of 70°F or less. Surface miners are more directly exposed to seasonal temperature changes. Henschel et al. (70) documented exposures of surface miners in working heavy equipment. This study notes the importance of acclimatization in preparing the body for hot environments. Hypothermia can occur from exposure to conditions well above freezing. The lethal deep body temperature is approximately 78°F. Thus, hazards may exist where a worker is immersed in cold water, exposed to cool, high velocity winds, in a state of physical exhaustion, or has insufficient food. There are no convenient indices relating cold to physiological response (71). It is concluded that surface mines entail more cold/heat stress conditions than underground mines. However, with proper adjustments in work practices and equipment the health effects of temperature are controllable.

It is not known whether adjustments in work practices to accommodate hot environments will reduce productivity and whether increases in coal mining employment which would bring into the work force persons who are unacclimatized and unaware of heat and cold hazards will significantly increase these adverse health effects.

There is a need for a better understanding of the longterm effects of exposure to hot and cold environments in coal mining and for a simple method for measuring the metabolic heat generated in the body during work.

## **Projected Health Effects of Increased Coal Production**

In order to estimate possible health effects of increasing coal production, data from the second round of the NIOSH National Study of Coal Workers' Pneumoconiosis have been used as the best recent estimate of respiratory disease among underground coal miners. The estimates presented here assume a rate of coal production as shown in Table 3 under the National Energy Plan (NEP) as compared

**Table 3. Annual environmental analysis report for national energy plan (NEP) compared to "business as usual" (BAU).**

	1975	1985	2000
Coal production (quads)			
Underground			
BAU	7.3	10.8	13.3
NEP	7.3	9.8	15.7
Surface			
BAU	7.9	13.2	24.7
NEP	7.9	18.3	29.2
Total			
BAU	15.2	24.0	38.0
NEP	15.2	28.1	44.9
Coal production relative to 1975			
Production			
BAU	1.00	1.58	2.50
NEP	1.00	1.58	2.95
Surface, %	52	55	65
BAU	52	55	65
NEP	52	65	65
% of increment from surface			
BAU	—	60	74
NEP	—	81	72

to business as usual (BAU) based upon data from the Annual Environmental Analysis Report (AEAR) published by the Energy Research and Development Administration (72). The AER assumes an 85% increase on coal production under the NEP in the year 1985 compared to 1975, expressed in quads, which corresponds to an annual coal production of 1130 million tons. It should be noted that other estimates of coal production in 1985 under the NEP by the American Gas Association, the National Coal Association, the United States Congress and the Department of Energy range from 850 to 1,265 million tons per year. Accordingly, a range of uncertainty from -25% to +12% exists for the estimates in Table 4 depending upon how much coal is actually produced in 1985.

It is important to appreciate that these estimates depend upon observations made between 1973-75 and, therefore, reflect mine conditions (dust levels) and population characteristics including number of years worked underground, smoking patterns, age, race, sex, etc. of that in the study mines between 1973-75. These mining and population characteristics are changing with lower mine dust levels (following passage of the Federal Coal Mine Health and Safety Act of 1969) and a younger work force, both factors which in the future would tend to reduce the rates observed between 1973-75. Therefore, it is likely that the figures shown in Table 4 are somewhat overestimated. Conversely, it is important to appreciate that this data is prevalence data which ignores men who have left the mines and who may well have higher rates of occupationally induced respiratory disease. In addition, it should be appreciated that the current and projected prevalence of chronic bronchitis, dyspnea and airways obstruction is only in part attributable to coal mine dust exposure as other factors such as smoking also play a significant etiological role. On the other hand, newly emphasized coal mining technologies such as long wall mining and the introduction of diesels into coal mining on a large scale represent unknowns which may act to increase the health risk associated with coal mining. To the extent which newly emphasized mining technologies such as diesels may increase efficiency, thus decreasing the number of miners required to produce a given quantity of coal, this may be a factor tending to reduce the total future health costs among coal miners. The figures in Table 4 do not depict much of a difference in health effects in 1985 under the National Energy Plan compared to business as usual. This is because, although more total coal will be produced under the National Energy Plan, a greater fraction of this coal is expected to be derived from surface mines which pose

**Table 4. Projected health effects of increased coal production with national energy plan and business as usual estimates.**

Estimate	Type	Production		No. employees	No. cases of CWP <sup>a</sup>	Cases of chronic bronchitis <sup>a,b</sup>	Cases of severe dyspnea <sup>a,b</sup>	Cases of airway obstruction <sup>a,b</sup>
		10 <sup>6</sup> tons	Quads					
1975	Underground	279	7.3	139,500	18,100	41,800	11,200	41,800
	Strip auger	332	7.9	52,500	1,300	15,700	4,200	10,000
	Total	611	15.2	192,000	19,400	57,500	15,400	51,800
1985, NEP	Underground	395	9.8	197,500	25,600	59,200	15,900	59,200
	Strip auger	735	18.3	116,000	2,900	34,800	9,300	22,100
	Total	1,130	28.1	313,500	28,500	94,000	25,200	81,300
1985, BAU	Underground	435	10.8	217,500	28,200	65,200	17,500	65,200
	Strip auger	530	13.2	84,000	2,100	25,100	6,700	16,000
	Total	965	24.0	301,500	30,300	90,300	24,200	81,200

<sup>a</sup>Not mutually exclusive.

<sup>b</sup>Not necessarily due solely to coal dust inhalation.

less of a health hazard than underground mines.

The main purpose in making these projections for 1985 is to note what the future health experience for coal miners may be if strong preventive measures are not maintained and increased to control coal mine dust under either the NEP or the BAU scenarios. Hopefully the recently enacted Federal Mine Safety and Health Act of 1977 will provide additional impetus for the control of hazardous exposures in coal mining.

## Safety Aspects of Coal Mining

This subject is reviewed in a monthly publication, "Coal Mine Injuries and Worktime," published by the Mining Enforcement and Safety Administration (MESA) (73). Coal production for surface and underground mines has, however, been included in that publication only since January 1977. For the purposes of this report, previous years' production figures were obtained for disabling injuries and deaths from MESA files. The data are summarized in Table 5. Principal causes of fatalities in underground mines are roof falls, haulage-related accidents and other machinery-related accidents.

These data can be used to estimate disabling injuries and fatalities associated with increased coal production. These estimates assume a rate of coal production as shown in Table 3 under the National Energy Plan (NEP) as compared to business as usual (BAU) based upon data from the Annual Environmental Analysis Report (AEAR) published by the Energy Research and Development Administration (72). The AEAR assumes an 85% increase in coal production under the NEP in the year 1985 compared to 1975, expressed in quads, which corresponds to an annual coal production of 1130 million tons. It should be noted that other estimates of coal production in 1985 under the NEP by the American Gas Association, the National Coal Association, the United States Congress and the Department of Energy range from 850 to 1265 million tons per year. Accordingly, a range of uncertainty from -25% to +12% exists for the estimates in Table 6, depending upon how much

coal is actually produced in 1985. The main purpose in stating these projections is to note what the future safety experience for coal miners may be if strong preventive measures are not taken to reduce safety hazards under either NEP or the BAU. To the extent that newly emphasized mining techniques such as diesels may increase efficiency, thus decreasing the number of miners required to produce a given quantity of coal, this may be a factor tending to reduce the total accident-associated deaths and disabling injuries among coal miners. However, neither the health effects nor the productivity of diesels are well understood at this time. The data in Table 6 do not depict much of a difference in 1985 under NEP compared to the BAU. This is because, although more total coal may be produced under the NEP, a greater fraction of this coal is expected to be derived from surface mines, which pose less of a safety hazard than underground mines. The recently enacted Federal Mine Safety and Health Act of 1977 should provide additional impetus for control of safety hazards in coal mining.

Several factors may tend to produce higher fatalities and injuries than are estimated above, however, a large number of inexperienced miners entering the work force may well drive the fatality and injury rates up. Construction of new underground mines would require more construction crews, thus altering the overall injury experience associated with those mines.

It may be concluded that surface mining operations produce fewer injuries per ton produced than underground mines. Principal causes of fatalities in underground mines are roof falls, haulage-related accidents, and other machinery-related accidents.

The use of diesel-powered equipment is a current issue which appears to have some safety ramifications. Reduction of electrically-powered haulage equipment may reduce electrical shock incidents, fires, and explosions but this has not been fully quantitated. However, if electrical equipment were handled properly, electrical hazards could be reduced. Although surface mines do produce fewer injuries per ton, most surface mine reserves contain

Table 5. Number of disabling injuries and deaths in coal mine operations per year.

Year	Surface mining			Underground mining		
	Fatalities	Nonfatal disabling injuries	Production, 10 <sup>6</sup> tons	Fatalities	Nonfatal disabling injuries	Production, 10 <sup>6</sup> tons
1973	17	1264	272.08	105	9206	285.87
1974	26	1267	301.81	97	6689	263.96
1975	35	1760	332.48	111	8687	278.65

**Table 6. Estimated fatalities and disabling injuries associated with increased coal production.**

Circumstance	Type	Production		No. fatalities	No. disabling injuries
		10 <sup>6</sup> tons	Quads		
1975	Underground	279	7.3	111	8,687
	Strip auger	332	7.9	35	1,760
1985, NEP	Total	611	15.2	146	10,447
	Underground	395	9.8	157	12,300
	Strip auger	735	18.3	77	3,900
1985, BAU	Total	1,130	28.1	234	16,200
	Underground	435	10.8	173	13,500
	Strip auger	530	13.2	56	2,800
	Total	965	24.0	229	16,300

fewer BTU's per ton than underground mine reserves, necessitating the need for more tons of coal mined.

High energy automated mining systems require close integration of the coal miner and the mining equipment. Ergonomic studies, relatively unknown in coal mining operations, are essential to control other safety and health hazards in the mining environment. Pollutant/particle sensor technology, now available from space age technology, needs to be applied to computer controlled mine ventilation systems which would reduce both the hazard of mine ignition and explosions as well as respiratory hazards in the mining environment. Such systems may also reduce uncertainties in coal dust measurements associated with human error.

Definitive studies quantitating safety and production aspects associated with diesel and electrically powered mining equipment are needed, as are studies to assess the effectiveness of miners trained as emergency medical technicians in further reducing the toll from deaths and disabling injuries among coal miners.

## Health and Safety Aspects of Coal-Fired Power Plants

### Health Effects

There are approximately 1000 fossil-fueled steam generating plants in the United States. The number of coal-fired power plants in this country is about 550 (74). NIOSH is currently collaborating with the Tennessee Valley Authority, which operates 63 of these coal fired power plants, employing about 5,800 workers (75) in studying health effects associated with this form of coal utilization. Using this information a rough estimate of the total number of workers

employed in coal fired power plants in this country is 50,000.

There are two major types of coal fired boilers. The first, referred to as "balanced draft," is operated under a negative pressure. Most of the modern plants are of this type. In many of the older plants, however, the pressure in the boiler is higher than the pressure of the outside atmosphere. These types are known as "positive pressure" boilers (74). Since boilers expand and contract with changes in temperature, it is difficult to keep them completely sealed. When leaks occur in the positive pressure boilers, gases and particulates may escape into the work-room environment.

Potential exposures resulting from boiler leaks include SO<sub>2</sub>, SO<sub>2</sub> reaction products, (sulfates, sulfites), CO, NO, NO<sub>2</sub>, fly ash, unburned hydrocarbons, polynuclear aromatics including benzo(a)pyrene, and aldehydes. As there are limited occupational exposure measurements of gases or particulates within coal fired power plants, the hazard potential inside this workplace is not easily quantified. It should, however, be noted that SO<sub>2</sub> has been found to be a co-carcinogen when combined with benzo(a)pyrene.

The present OSHA SO<sub>2</sub> standard is 5 ppm; the proposed NIOSH standard is 0.5 ppm which should protect against alteration in mucous secretions, particle clearance, and airways resistance (76). An industrial hygiene survey of two positive pressure coal fired power plants shows that time-weighted average SO<sub>2</sub> exposures in excess of this proposed standard do occur. Most of the exposures in the power plant are short-term and intermittent with peak values higher than the 8-hr TWA measured with an SO<sub>2</sub> dosimeter (77). NIOSH has proposed a ceiling SO<sub>2</sub> exposure of 10 ppm on the reasonable supposition that high but intermittent exposures are equally if not

more hazardous than low-level chronic exposures (76).

More harmful than SO<sub>2</sub> itself are compounds that are formed from chemical reactions of SO<sub>2</sub> and other substances, i.e., sulfites, sulfates, sulfuric acid (78-80). Many of these compounds are more toxic than SO<sub>2</sub> alone and in the proper environment (which probably exists in power plants) can readily be formed from SO<sub>2</sub> or sulfur compounds and can be absorbed onto respirable particulate and transported deep into the lung (80-82).

Particulate in the form of fly ash contains trace elements and surface areas that theoretically could catalyze the conversion of sulfur dioxide to sulfites and sulfates. Fly ash (0.5-10  $\mu$ m diameter) is largely of respirable size, and is, therefore, preferentially deposited in the lung. However, one study has shown that SO<sub>2</sub> in the presence of insoluble fly ash, is neither oxidized nor adsorbed at room temperatures and high relative humidity (83). Trace elements in the fly ash of possible toxicological significance (apart from their role as a catalyst and/or carrier of toxic gases) include silica, beryllium, lead, cadmium, arsenic, selenium, thallium, antimony, and vanadium, (84).

The conversion of molecular nitrogen into nitrogenous compounds takes place thermally in flames explosions, and electrical discharges where nitrogen and oxygen combine to form nitric oxide. At normal temperatures, nitric oxide reacts with air to form nitrogen dioxide (85). It is, therefore, possible that oxides of nitrogen are present in flue gas leaks. Stack emission data shows that there is more NO<sub>x</sub> formed in coal fired power plants than gas or oil fired plants (86). It seems reasonable to assume, therefore, that NO<sub>x</sub> would be a greater hazard in coal-fired plants.

The nitrogen oxides of potential concern are nitric oxide and nitrogen dioxide. The National Institute for Occupational Safety and Health recommends a standard of 25 ppm TWA 8-hr exposure for NO, and a ceiling concentration of 1 ppm for NO<sub>2</sub>. Nitrogen oxides are not very water-soluble and, therefore, are deposited largely in the pulmonary regions. NO and NO<sub>2</sub> probably react with water in the lung to form nitrous and nitric acid, which in sufficient concentration will produce pulmonary edema. NO<sub>2</sub> has been suggested as a possible causative agent in emphysema (87). Welding operations which take place at these plants may also result in the formation of NO<sub>x</sub>.

Since carbon monoxide is formed during incomplete combustion, there is a potential exposure to this compound as a result of boiler leaks, especially during start-up and shut-down operation. Another potential for exposure to CO would be from smould-

ering fires which sometimes occur when coal is stockpiled for any length of time.

Unburned hydrocarbons have been measured in the stack emissions from coal fired power plants. Hydrocarbons are also emitted from power plants burning natural gas and oil. The compounds of greatest health concern are the polynuclear aromatic hydrocarbons which include carcinogens such as benzo(a)pyrene. Aldehydes which are primary irritants have also been measured in the emissions of coal- and oil-fired power plants (88, 89).

Coal dust exposure may occur in all stages of coal handling at coal fired power plants. A good deal of work has been done to document the effects of coal mine dust on respiratory disease (25, 28-36). Results of a study of dust exposure in surface coal mines suggest these observations may apply to comparable dust levels experienced in other coal handling situations. Exposure to coal-dust during physical-coal cleaning and to coal dusts and solvents during chemical-coal cleaning must also be considered potential problems.

Asbestos is used as a thermal insulating material in certain areas of power plants. Exposure in excess of NIOSH recommended limits (0.1 fiber/cm<sup>3</sup>) may occur at areas where insulation is being removed or applied. Exposure could best be avoided by using other insulating materials wherever possible. Although asbestos is a significant health hazard wherever it is used, its use is not unique to coal fired power plants.

Two problems that are readily apparent in coal fired power plants are noise and heat. Noise is a significant problem at the crushing operations, in the turbine room, and to a lesser extent in the boiler bays. Since it is usually quite difficult to implement engineering controls for noise at existing plants, and because of the difficulty in convincing workers of the necessity for personal protective equipment, noise continues to be a serious problem. Heat stress is a problem around the boiler bay areas, especially on the upper levels. During certain maintenance operations, workers may be exposed to heat at levels which could result in heat stress symptoms, e.g., heat exhaustion, heat cramps. Except for coal dust, all of these potential problems are experienced to some degree in all fossil fueled power plants.

In order to convert gas or oil fired boilers to coal, the biggest problems encountered are in the development of coal handling capabilities. This usually involves the installation of crushers, conveyors, and coal feeders demanding significant support from general construction workers, welders, painters, etc. Boiler modification may also necessitate the removal and re-installation of insulating materials

which may result in increased exposure to asbestos, mineral wool, or other insulating materials. Exposure to dust and noise, common in coal handling systems are generally not encountered in oil or gas handling systems.

It is concluded that noise, heat, coal dust, asbestos, fly ash and SO<sub>2</sub> are potential problems in coal fired power plants. Balanced draft boilers are less hazardous in terms of fly ash and flue gas exposure when compared to the positive pressure type boilers.

There is uncertainty whether NO, NO<sub>2</sub>, CO, sulfur compounds (other than SO<sub>2</sub>), fly ash, polynuclear aromatics, and aldehydes are present in coal-fired power plants at levels that might impair health.

Research needs include (1) identification of sulfur compounds, other than SO<sub>2</sub>, in coal-fired power plants and determination of any deleterious effects at existing levels; (2) determination of presence of NO<sub>2</sub>, NO, CO, unburned hydrocarbons, polynuclear aromatics, and aldehydes and evaluation of possible health effects; (3) gathering of quantitative and qualitative information on fly ash constituents; (4) determination of whether flue gases are being adsorbed on fly ash particulate and the investigation of possible health consequences; (5) development of personal sampling methods where they now do not exist, i.e., SO<sub>x</sub>, NO<sub>x</sub>, CO for the determination of dose-response relations; (6) evaluation of mortality patterns among those exposed to combinations of asbestos and coal dust with particular attention to carcinogenic risks.

## Safety Aspects

Data from the Tennessee Valley Authority indicate the most prevalent safety problem encountered in coal fired power plants is foreign objects in the eye. This is due to airborne coal dust and fly ash prevalent at these facilities. Other safety problems in order of prevalence are: sprains and strains; contusions due to slips and falls; lacerations; burns from hot pipes, steam vents, etc.; fractures. Most accidents occur during maintenance operations rather than during normal operation. Of the two general maintenance categories (mechanical and electrical), most accidents occur during mechanical maintenance (90). Except for foreign objects in the eye, one would expect that similar problems would be present in oil and gas fired power plants. It should be noted that NIOSH has been working with the electric utility industry in preparing a comprehensive occupational safety and health program for that industry. It is recognized that injuries associated with coal fired power plants are less severe than injuries associated

with coal mining, but are mentioned for the sake of completeness.

## Training

The discussion in this paper has highlighted a number of training needs for coal miners, as well as for health and safety professionals, as a result of future commitments toward increased coal production. Among the major training needs for coal miners are the following: (1) increased safety and health training for inexperienced coal miners entering the workforce (The recently enacted Federal Mine Safety and Health Act of 1977 provides additional impetus for such training); (2) further training of coal miners as emergency medical technicians; (3) advanced training for coal miners to develop selected health and safety expertise.

Among the major training needs for health and safety professionals is increased training of newly graduated industrial hygienists, physicians, nurses, mining engineers and safety professionals knowledgeable in the health and safety aspects of all phases of coal mining and coal utilization. New graduates with this expertise will be urgently needed for employment in industry, government and academia as our nation's reliance upon coal increases. Also needed is upgrading of the skills of existing health and safety professional so that they may apply these skills to identify and solve health and safety problems associated with increased coal production.

The new NIOSH Educational Resource Centers and the Federal Mine Safety and Health Act of 1977 provide both an impetus and an opportunity for professional training in coal mine occupational safety and health.

## Conclusions

This review of occupational health and safety aspects of increased coal production supports the conclusion that without strong preventive health and safety measures, increasing coal production cannot be achieved without incurring additional costs in occupationally induced disease, job related disabling injuries, and accidental deaths. Greatly increased production of coal in the United States will expose larger numbers of workers to the health and safety hazards of coal mining. Although conditions in the coal mining industry have improved as a result of the Federal Coal Mine Health and Safety Act of 1969, considerable doubt exists about the achievement of maximum compliance.

Underground coal miners experience increased mortality from both occupationally induced lung dis-

ease and accidental deaths. In addition, there is a possible increased risk of death from stomach cancer among underground coal miners. Underground coal mining poses a greater health and safety risk than surface mining. Exposure to noise is also greater in the confined spaces of underground mines. Two newly emphasized coal mining technologies, the use of diesel powered mining equipment and the use of long wall mining techniques may be associated with potentially serious health effects. The occupational safety and health aspects of coal mining are understood well enough today to justify implementing the necessary control measures so that potential problems associated with increased coal production do not become greater problems in the future.

The recently enacted Federal Mine Safety and Health Act of 1977 should provide additional impetus for the control of health and safety hazards in coal mining.

Finally, it should not be forgotten that there may be added occupational safety and health hazards associated with increased coal utilization in coal fired power plants. These are primarily of a respiratory nature (coal dust,  $\text{SO}_x$ ,  $\text{NO}_x$ , asbestos), but also include exposure to noise and safety risks.

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